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## **Prioritizing Acquisition Paths under the State-Level Concept**

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### **Abstract**

Under the International Atomic Energy Agency's State-level concept, the implementation of safeguards in any particular State with a Comprehensive Safeguards Agreement is informed by an analysis of all technically plausible paths by which the State could pursue acquisition of material for a nuclear explosive. The sequence of path steps that make up potential acquisition paths may involve diversion of declared nuclear material, misuse of declared nuclear facilities for undeclared production or processing of nuclear material, undeclared import of nuclear material, establishment and operation of undeclared nuclear facilities, or combinations of these strategies. Each path step, and by extension each potential acquisition path, is assessed in terms of the ease and speed with which the State could accomplish, it in light the IAEA's analysis of information about the State's nuclear fuel cycle and related technical capabilities. This in turn can guide the setting of priorities for safeguards coverage of acquisition paths, including the establishment of timeliness goals. This paper discusses work funded by DOE/NNSA's Next Generation Safeguards Initiative to explore, including via case studies, practical methods for assessing and prioritizing acquisition paths.

### **Acquisition Path Analysis in the Context of the State-Level Concept**

With the goal of maintaining effective and efficient safeguards in a time of static budget and growing safeguards demands, and to make international safeguards more fully information-driven and adaptable, the International Atomic Energy (IAEA) is working to further evolve the State-level concept (SLC). The SLC places relatively less emphasis on mechanistically implementing check-list criteria at the facility level, and more emphasis on technical objectives that derive from considering the State's nuclear program as a whole, not just as a collection of nuclear facilities and nuclear material inventories.

A central feature of this evolving State-level concept is that the IAEA would, for each State with a safeguards agreement in force, develop a customized State-level safeguards approach (SLA) designed to meet technical objectives that derive from a structured, State-specific technical assessment of potential acquisition paths.\* The steps that make up

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\* An acquisition path is a sequence of activities (or "path steps") by which the State could, from a technical point of view, acquire weapons-usable nuclear material for use in a nuclear weapon or other nuclear explosive device.

acquisition paths may involve the diversion of declared nuclear material, the misuse of declared nuclear facilities for undeclared production or processing of nuclear material, the undeclared import of nuclear material, the establishment and operation of undeclared nuclear facilities, or combinations of these strategies.

Acquisition path analysis in this context serves several purposes: (1) to prioritize acquisition paths in light of the ease and speed with which they could be accomplished by the State, thus informing the setting of path-level detection probability and timeliness goals; (2) to identify specific technical objectives for detection of activities along each path; and (3) to provide a framework for evaluating whether a proposed State-level safeguards approach provides coverage of paths commensurate with their priority.

The number of acquisition paths can be large because of the different types of potential starting material and the different fuel cycle process that could be used to transform a given starting material to nuclear-weapon usable form through one or many subsequent processes, as described for example in the IAEA's Physical Model.<sup>1</sup> *Although the same Physical Model is applicable to all States, the number of physically possible paths will differ from State to State*, depending on what types and forms of declared nuclear material and declared nuclear facilities are present in the State. For example, paths that begin with diversion of declared unirradiated direct-use nuclear material would not be possible a State without such declared nuclear material, nor would paths involving the misuse of a declared enrichment plant be possible in a State without a declared enrichment plant.

*Not only will the set of physically possible paths differ from State to State, so too will ease and speed with which States can, from a technical-capability perspective, carry out a given acquisition path.* For example, a State with no experience in spent-fuel reprocessing or in large hot-cell operations, and with little chemical engineering or industrial capability, would be expected to require more time and effort to establish and successfully operate an undeclared reprocessing facility than would a State with an existing declared reprocessing facility or with relevant past experience in the technology.

With a view to supporting the IAEA Secretariat's ongoing development work in this area, the U.S. Department of Energy's Next Generation Safeguards Initiative (NGSI) has funded research studies at Lawrence Livermore National Laboratory and Los Alamos National Laboratory to develop and test applicable methods for acquisition path analysis and for the design of State-level safeguards approaches. These studies have used concrete sample problems, including fictional but representative test cases, to explore the benefits, limitations, and practical workability of various candidate methodologies. The intent of this paper is to highlight some general lessons about desirable features to consider including in whatever method the IAEA adopts.

## Visualizing and elaborating potential acquisition paths

Acquisition paths can be described at various levels of detail, depending for example on whether different variants of a general class of facility, material type, or fuel cycle process are lumped together or treated as distinct. In any case the granularity should be fine enough to capture distinctions that matter for safeguards implementation. If the resulting number of paths is large, SEGs may find it convenient to visualize as a group “families” of paths having important common features (e.g., all paths involving the production of high-enriched uranium in a clandestine enrichment plant.)

There are many ways to represent acquisition paths. In its simplest form, a path could be described as a sequence of steps. For example, for a hypothetical State with indigenous uranium production, a declared natural uranium fuel fabrication plant, and a declared, natural uranium fueled power reactor, among the potential acquisition paths would be the one consisting of these four steps:

1. Diversion of natural  $\text{UO}_2$  from the declared fuel fabrication plant
2. Fabrication of targets in an undeclared installation
3. Misuse of a declared reactor for undeclared irradiation of the targets
4. Separation and recovery of plutonium in an undeclared reprocessing facility.

To ensure a more systematic treatment, and to facilitate and subsequent analysis of a possibly large number of acquisition paths, it is convenient to represent the network of paths in terms of a graph with nuclear material types/forms as the nodes and with edges representing the State actions that acquire or transform material.<sup>2</sup> For example, the sequence of four path steps described above could be represented as shown in Figure 1.

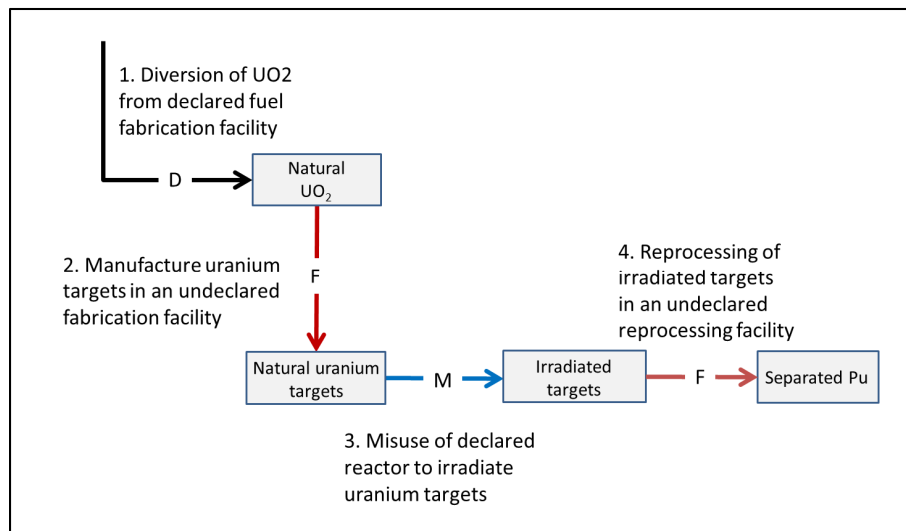


Figure 1. A four-step acquisition path shown as a directed graph, where the edges of the graph are State actions that acquire, produce, or process nuclear material.

Figure 2 shows a higher-level view of the acquisition path network for a State with a full fuel cycle, including declared enrichment and reprocessing facilities and stocks of unirradiated direct-use nuclear material. If elaborated in greater detail, such a graph could include tens of nodes, scores of edges, and hundreds or more different possible paths to the acquisition of unirradiated direct-use material.

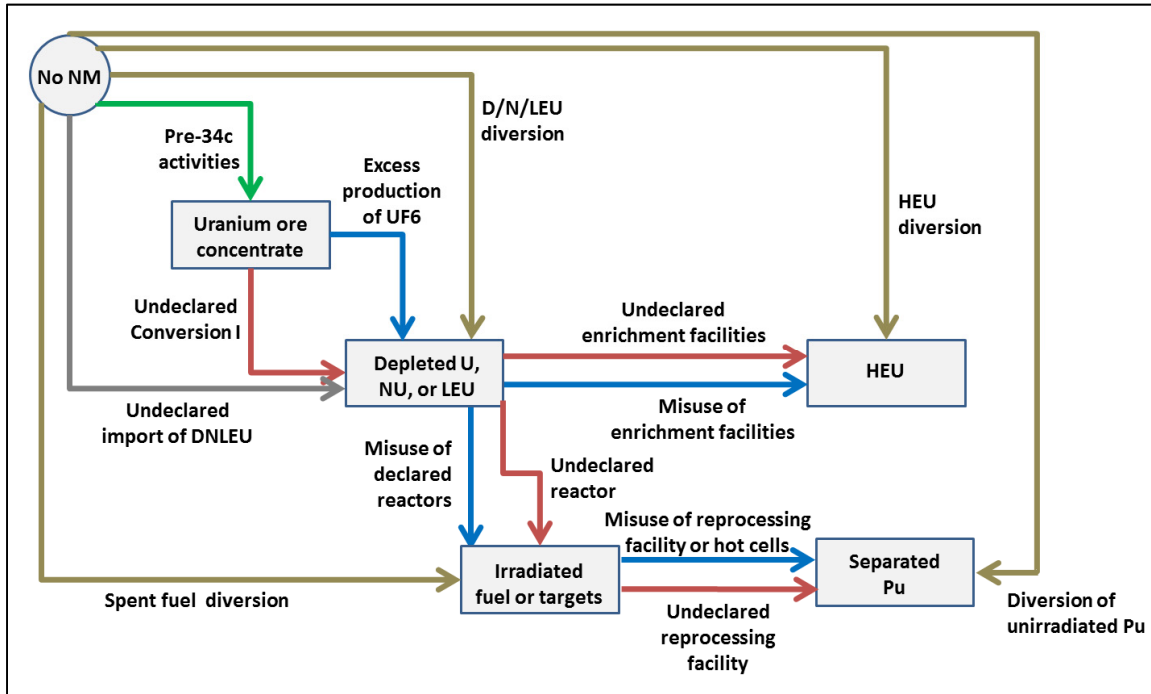


Figure 2. High-level view of the acquisition-path network for a full-fuel-cycle State.

### Analyzing acquisition paths in terms of technical plausibility

Under the State-level concept, each potential acquisition path is assessed in terms of its State-specific “technical plausibility,” that is, the ease and speed with which the State in question could accomplish it in light the IAEA’s analysis of information about the State’s nuclear fuel cycle and related technical capabilities. This analysis informs the level and timeliness of safeguards coverage that is required in order to provide adequate deterrence through risk of early detection before completion of the path.

Acquisition path analysis is performed by State Evaluation Groups (SEGs).<sup>†</sup> In the interest of ensuring non-discrimination among States, it would be desirable for SEGs to

<sup>†</sup> For each State, a cross-departmental multidisciplinary State Evaluation Group, headed by the Country Officer from the relevant Division of Operations, performs ongoing, collaborative analysis of information about a State’s nuclear program, including feedback from inspection activities, not only to identify questions and inconsistencies requiring follow-up and to recommend safeguards conclusions, but also to “determine the safeguards activities that need to be conducted with respect to that State in order to maintain those conclusions.” [GC(55)/16, 26 July 2011, p. 4]

apply a consistent method of evaluating technical plausibility, so that the results obtained for a given State are reasonably reproducible, and so that the yardstick for assessing technical plausibility (and hence for assigning priority for safeguards coverage) would be consistent across States. This requires a method to assess the technical plausibility of individual path steps and of entire paths, and in our case studies we explored the advantages and disadvantages of various approaches.

*The importance of State evaluation.* In order to have a sound basis for evaluating potential acquisition paths, the SEG should draw on a current, comprehensive assessment of the State's nuclear program and related technical capabilities. This includes not only the State's declared nuclear facilities and declared nuclear materials, but also its past and current R&D program and its scientific, technical, and industrial capabilities that would affect its potential capability to carry out hypothetical path steps, including the construction and operation of undeclared nuclear facilities of various types. The SEG's assessment should note inconsistencies or other possible indications of undeclared nuclear activities, as well as any unresolved non-compliance with safeguards obligations. SEGs should characterize uncertainties with respect to the status of, or possible existence of, capabilities in all areas of the fuel cycle, taking account of the quality of information available to the Agency through its inspection activities, State reports, other Safeguards and Agency information sources, and external information.

*Prioritization Approach.* As a preliminary step to prioritizing acquisition paths, the analysis first evaluates the technical plausibility of individual path steps. This approach has the advantage that a given path step may be part of many different acquisition paths, and the number of possible path steps is in most cases significantly smaller than the number of acquisition paths that can be formed from those steps. Once the path-step-level evaluations are complete, it is relatively straightforward to evaluate paths as a whole, even if the number of paths is large, by taking advantage of graph analysis tools, for example.

*Assessing individual acquisition path steps.* Because acquisition path steps can be any of several types (i.e, diversion, misuse, processing in undeclared facilities, undeclared imports), it is appropriate to specify separately the assessment criteria to be used for each type. In several of our case studies, we used the following attributes as a basis for scoring the technical plausibility of the different path-step types:

- For nuclear material *diversion* steps, we assume the State has the capability (from a purely technical perspective, not taking into account the risk of detection) to accomplish the act of diversion, so the path step assessment should focus on the *quantity of material available* (in SQ) for diversion. We assigned a plausibility score from 0 to 1, using either a smooth continuous curve or stepwise bins, as shown in Figure 3.

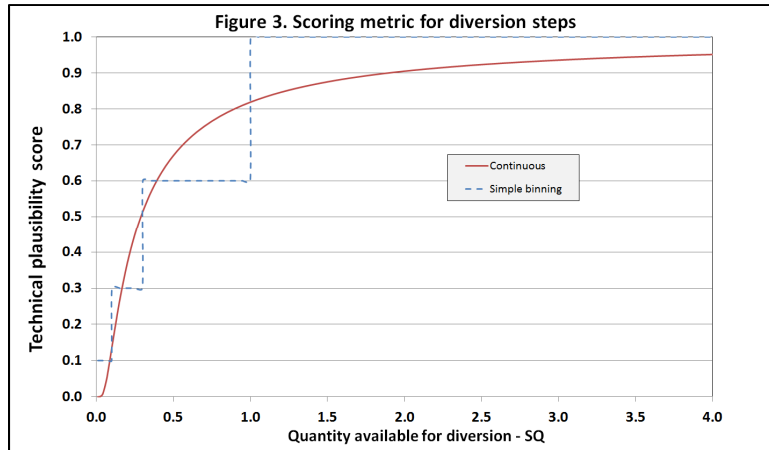


Figure 3. Possible stepwise and continuous value functions for scoring diversion-type path steps based on the quantity of material available

- For misuse steps, one could assess technical plausibility on the basis of the potential production rate of undeclared product if the facility were misuse, for example using as a metric the time required to produce 1 SQ through misuse (Figure 4).

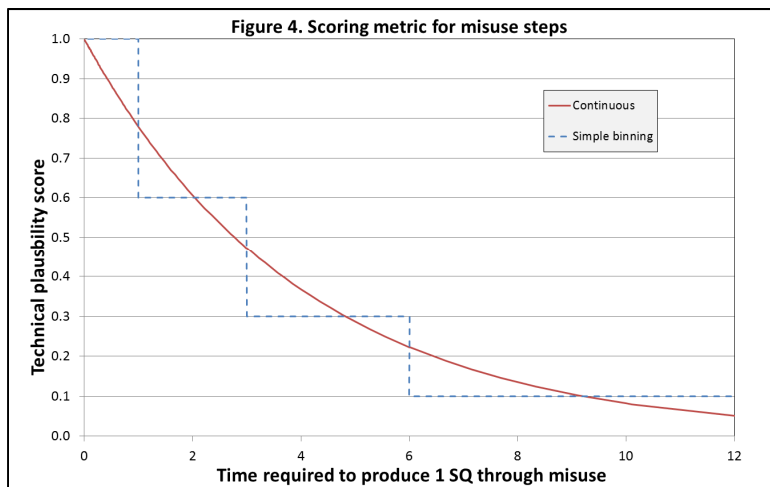


Figure 4. Possible stepwise and continuous value functions for scoring facility-misuse-type path steps, based on the time required to produce 1 SQ

- For steps involving hypothetical undeclared facilities, the analysis would rely in part on the expert judgment of SEGs. We have explored various approaches to assessing this type of path step. One approach would simply characterize the State's ability to construct and operate such a facility in qualitative terms, e.g., low, medium, or high. Another approach would be to estimate, albeit in rough terms, the time required to complete the step, and to assign a plausibility score that would be high for short lead times and low for long lead times, as in Figure 5.

- For a State where the SEG could not rule out with reasonable assurance the existence of a completed, clandestine facility ready to receive and process material, the time would be simply the estimated processing time, as short as months in some cases.
- To the extent that the Agency's safeguards activities and analysis provided confidence that no such undeclared facility currently existed in the State, the estimate could take into consideration the time needed to construct and commission the facility.
- Finally, for a State where the IAEA's analysis led it to conclude that the State still lacked the necessary technical foundation to begin building such a facility without additional R&D or acquisition of additional expertise, SEGs could also take into consideration that additional lead time would be needed.

This approach of evaluating undeclared-facility steps in terms of time would have the advantage of capturing and documenting judgments that could guide the setting of timeliness requirements for detection of diversion upstream of the undeclared-facility step.

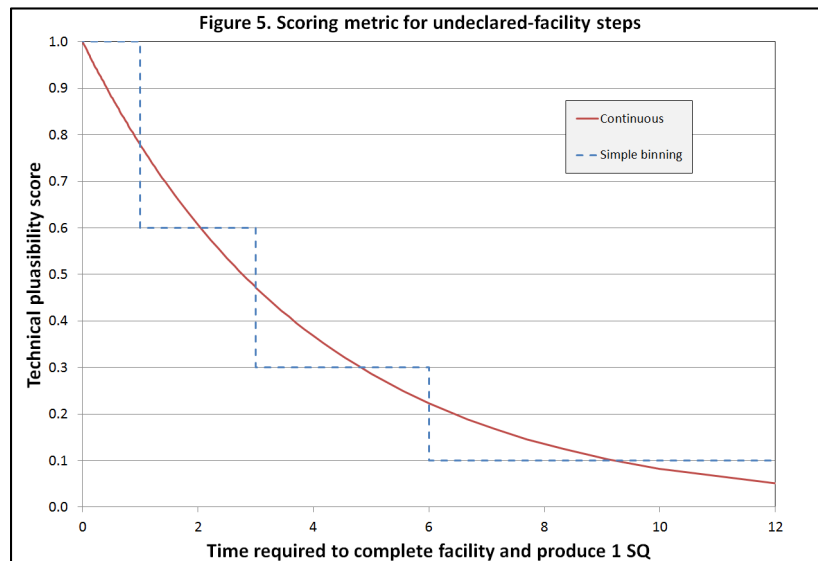


Figure 5. Scoring metrics for undeclared-facility steps based on estimated time to construct the facility and produce 1 SQ

- For steps involving *undeclared import of nuclear material*, it is difficult to characterize a State's capacity to obtain nuclear material of various types and quantities from suppliers able to provide it and willing to forego reporting its export to the IAEA. We postulate that more sensitive nuclear materials would be more difficult obtain secretly, but for now this remains a topic for future study.

Assessing the technical plausibility of acquisition paths. Having assigned a qualitative or quantitative score to each path step in the set of possible acquisition paths, the scores can be combined in some fashion to obtain a measure of that path's plausibility for the State from a technical-capability perspective. We experimented with various means of propagating path-step scores along acquisition paths, and most produced reasonable results in our judgment.

For each path, we also estimated the minimum "path time" for the State to complete the path. This estimate is not just the sum of individual path-step time estimates, but rather takes account of the possibility that some steps could overlap in time. (For example, for a path involving diversion of low enriched UO<sub>2</sub>, conversion of that material in an undeclared UF<sub>6</sub> conversion facility, and enrichment of that material to HEU in an undeclared conversion facility, construction of the conversion facility could begin well before the conversion facility was complete and had processed diverted UO<sub>2</sub> to UF<sub>6</sub>.)

The output of the acquisition path analysis is a set of acquisition paths evaluated with respect to their attractiveness in terms of the State's technical capability to execute them and the time that would be required. These results can be used to set path-level detection probability and timeliness targets to be satisfied by the State-level safeguards approach.

### **Prioritizing technical objectives**

As described previously by IAEA officials<sup>3</sup> and by other papers in this session, the results of acquisition path analysis are used to establish specific safeguards technical objectives (e.g., "detect irradiation of undeclared uranium targets," "detect undeclared reprocessing of targets in post-irradiation examination hot cells," etc.) associated with specific acquisition path steps. Development of a State-level safeguards approach requires identifying safeguards measures applicable to each objective and allocating resources to those measures in a way that is cost-efficient while also providing effective safeguards coverage of each acquisition path commensurate with its technical plausibility.

One method for accomplishing that task would be to model the cost and detection power of each candidate safeguards measure as a function of the frequency and intensity of its application, and to use software to arrive at an optimized, most cost-efficient, State-specific solution that, according to the model, would cover the set of acquisition paths for that State to the required degree of effectiveness.<sup>4</sup> A possible drawback of that approach is that State Evaluation Groups would be a step removed from the analysis, so it could be important to understand how sensitive the results are to key assumptions.

As a complement or alternative to such a global optimization approach, one could, as suggested in some IAEA papers and presentations,<sup>5</sup> prioritize the individual technical objectives first, on the basis of parameters that would approximate the same factors that

would influence the outcome of an explicit optimization calculation. In general, one would expect to assign the highest safeguards-coverage priority to technical objectives associated with path steps that:

- Are closest to the end of a path (because they involve materials and processes that are more strategic, and because they are potential choke points for detecting many different potential paths that ultimately pass through them)
- Are easiest for the State to accomplish (because technical difficulty presents less of a barrier)
- Are most amenable to cost-effective detection through IAEA measures

In this way, one could prioritize technical objectives on the basis of proximity to weapons material, the State's technical capability to accomplish the path step that the technical objective seeks to detect, and the availability of cost-effective safeguard measures, and could use the results of that prioritization to set performance targets for accomplishment of those objectives.

## **Conclusions**

Based on the several case studies we explored, it appears that any of several self-consistent methods could be used for prioritizing acquisition paths, as long as the methods satisfy some general principles such as granularity appropriate to the complexity of the State's fuel cycle and careful treatment of uncertainties.

In evaluating path steps that involve processing of nuclear material in hypothetical undeclared nuclear facilities, it will be important for SEGs to have a consistent, defensible means for assessing the time that would be required for the State to accomplish the step. This includes not just time to process material in a completed clandestine facility but also the time that would be required for construction and commissioning of such a facility and, in the case of States with limited technical capabilities and fuel-cycle experience, the time that would be needed to complete necessary R&D and build up a capability. (Such estimates would have to take account of the risk that clandestine foreign assistance could in some cases reduce the timeline.) To that end, it might be useful as a topic for future research to explore the feasibility of establishing guidelines for assessing the minimum plausible lead times to attainment of various fuel cycle capabilities based on various characteristics of a State's nuclear and related technical capabilities and scientific-industrial infrastructure.

In the final analysis, one can't really escape need to rely on expert judgment in the process of acquisition path analysis. For that reason it will be important for the Agency to maintain robust internal peer review, management review, and quality management practices to ensure that those judgments remain sound and objective.

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<sup>1</sup> IAEA Safeguards Technical Report No. STR-314 (May 1999)

<sup>2</sup> See, for example C. Listner, M.J. Canty G. Stein, A. Reznicek, and I. Niemeyer, "A Concept for Handling Acquisition Path Analysis in the Framework of IAEA's State-level Approach," Proc. 53rd INMM Annual Meeting (2012)

<sup>3</sup> J. Cooley, B. Moran, and H. Nackaerts, "Moving towards a Safeguards System that is Fully Information Driven," Proceedings of the 52<sup>nd</sup> INMM Annual Meeting, Palm Desert, CA, USA, July 2011; J. Cooley, "IAEA State Level Concept," presentation of the ESARDA Joint Meeting on "IAEA State Level Concept," Ispra, Italy, 12 November 2013

<sup>4</sup> C. Lister et al., op. cit.

<sup>5</sup> J. Cooley, et al, op. cit.